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Finding economic optimality in leakage reduction: a cost-simulation approach for complex urban supply systems

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Abstract

The optimal economic level in leakage reduction must be defined when reaching equilibrium between marginal costs of saved water and marginal costs of achieving additional reduction in leakage (Farley and Trow, 2003). This concept is used to deal with the question of what the target in reducing leakage should be and how related costs can be justified. Nevertheless, when negotiating for optimal decisions considering complex multi-centre (or multi-district) supply systems, subject to reduced water resources and reduced funds, the problem could be much more difficult to define and analyze. Mainly, in this situation, the optimal economic problem can be modified in finding the priorities in investment for leakage reductions between the centres in the supply network. This paper is related to these aspects; it mainly focuses on finding a reliable and correctly justified cost-function attribution for the water in multi-source and multi-centre systems.

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Keywords: Leakage reduction; Complex supply systems; Cost-simulation.

1. Introduction

As is well known, the concept of optimal economic levels in leakage reduction can be defined when reaching equilibrium between marginal costs of the saved water and marginal costs of achieving an additional reduction in leakage (Farley and Trow, 2003). This economic level of leakage is that at which any further reduction would incur costs in excess of the benefits derived from the savings (Lambert and Lalonde, 2005). The current thinking on

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optimal economic level is that each and every activity aimed at reducing leakage follows the *law of diminishing returns*, meaning 'the greater the level of resources employed, the lower the additional marginal benefit which results' (Pearson and Trow, 2005). The optimal level must consequently be settled within the context of the supply–demand balance for water. Frequently, the optimal-level concept is used to deal with the question of what the target should be in reducing leakage and how related costs can be justified. Nevertheless, when negotiating optimal decisions considering complex multi-centre (or multi-district) supply systems, the problem could be much more difficult to define and analyse, particularly if the system is constrained by reduced water resources and reduced funds. All in all, in this situation, the optimal economic problem can be modified in finding the priorities in investment for leakage reductions between centres in the supply network.

This paper is related to these aspects; it mainly focuses on finding a reliable and correctly justified cost-function definition for the supplied water in real and complex multi-centre systems. A graph-optimization approach is used to define optimal flows of water from sources to demand nodes in the supply system (Ahuja et al., 1993, 1999). The demand nodes can represent homogeneous district-distribution systems, or even different urban centres, connected in the supply system represented by the graph. A Cost-Simulation procedure is then developed, in order to define the incremental behaviour of water cost along the paths connecting each demand node to supply nodes. This procedure can be considered as a development for multi-centre urban supply systems with the approach used in Deidda (2003) to determine cost-flows in multi-reservoir systems. To optimize flows in the network and retrieve the min-cost flow distribution, the Cost-Simulation procedure is linked to the WARGI optimization DSS (Sechi and Zuddas, 2000; Manca et al., 2004; Sulis and Sechi 2012).

2. The Cost-Simulation procedure in water supply systems

Finding a reliable and correctly justified cost function of the water and dealing with optimization of economic levels of leakage in complex multi-centre systems is the main aim of this work. Using flows retrieved by the simulation model, the incremental cumulative evaluation of water costs are estimated along the paths coming from supply nodes to demand nodes in the graph of the supply system. At the end, it is possible to evaluate the water production costs related to each demand and to define the marginal benefits in saving water in order to find priorities in leakage reduction investments between demand centres.

Synthetically, the Cost-Simulation procedure can be summarized in four steps:

1. Water system definition and analysis;
2. Graph-based simulation modelling using WARGI;
3. Cumulative cost evaluation in the supply graph;
4. Incremental benefits and investment priorities evaluation for leakage reductions.

In the first step the hydrological, hydraulic, infrastructural, economic and functional features of the water-supply system are defined. Then, in the second step, the supply system is represented as an oriented graph using the input graphical interface of the simulation model WARGI-SIM (Sechi and Zuddas, 2000; Manca et al., 2004; Sulis and Sechi, 2012). WARGI-SIM retrieves optimal flows in the graph by considering the water system's priority and preference management rules. From simulation output and the economic data of water infrastructures, the procedure's third step evaluates the incremental cumulative of water costs along the paths connecting each supply-node to each demand-node. In this way, the water unitary production cost related to each demand node is retrieved. In the final step, priorities in investment are defined for leakage reductions in the supply system. Each step of the procedure will be described hereafter.

2.1. Water system definition and analysis

The hydrological, hydraulic and infrastructural features of the water system must first be identified. The analysis takes place in a management optimization context for the supply system and no new transfer works, treatments or special repairing expenses are considered, so no more than the usual management and ordinary repair and operative costs are evaluated for the supply system here. From the economic point of view, water production in the system can be characterized by two kinds of costs:

- Unit costs (UC_{ij}) associated with operating and linked to unit flows in the transfer work between nodes i and j;
- Annual costs (AC_{ij}) associated with management and linked to annual cost of the infrastructure maintenance.

In the procedure, to summarize in a unique economic feature both UC_{ij} and AC_{ij}, the basic unit cost (BC_{ij}) is considered to represent the total cost of the water transfer per cubic metre:

$$BC_{ij} = UC_{ij} + \frac{AC_{ij}}{QA_{ij}} \quad (1)$$

where QA_{ij} is the annual flow in the infrastructure connecting node i to node j. In dealing with optimality in economic levels of leakage, water systems are here hypothesized to be almost entirely equipped and new works are not expected. Therefore, it is mainly the operating and management costs of the existing infrastructures that are evaluated here.

2.2. Graph-based simulation modelling using WARGI-SIM

WARGI is a user-friendly decision support tool specifically developed to help users to understand the interrelationships between demands and resources when optimizing multi-reservoir water-supply systems and mainly considering resources in conditions of scarcity, such as those that frequently occur in Mediterranean regions. Since the mid-1990s, WARGI has been extended and new modules have been developed by the Water Research Group (WRG) at the University of Cagliari, Italy. The water allocation in WARGI-SIM is simulated using the user-defined preferences and priorities. Additionally, the user can define reserved volumes as a fixed function of the period of the year, and the withdrawal water from the reserved zone is decreased to satisfy user-selected high priority demands. WARGI-SIM is definitely a relatively simple-to-use simulation model that enables non-experts to understand the main issues and problems of complex supply water systems management by using a basic-graph representation and automatically constructing the multi-period network (Pallottino et al., 2005).

2.3. Cumulative cost evaluation in the supply graph

The cost-function evaluation along the paths connecting supply to demand nodes can be seen as following the concentration of a conservative marker (no decay) along the arcs of the water way: the ‘cost-concentration’ can be evaluated using cost balance equations at every node in order to update the cost value. The cost increases (or decreases) at each node along the paths considering water service costs associated with transfer arcs coming from predecessor nodes. For a generic node j, as in Fig. 1, the cumulative cost is simply given by eq. (2):

$$CC_j = \frac{\sum_{i=1}^{I} \left(CC_i + BC_{ij} \right) Q_{ij}}{\sum_{i=1}^{I} Q_{ij}} \quad (2)$$

where:
CC_j cumulative cost value at node j;
Q_{ij} water flow incoming to j from predecessor node i;
BC_{ij} basic unit cost of the water transfer i–j, as defined by eq. (1).

Therefore, the cumulative cost function in a node is given by the weighted average of the sum of CC_i of predecessor nodes and BC_{ij} of incoming arcs. The final result is the cumulative cost configuration at each node of the graph. In order to correctly evaluate eq. (2), an optimal flows configuration is requested by WARGI-SIM.

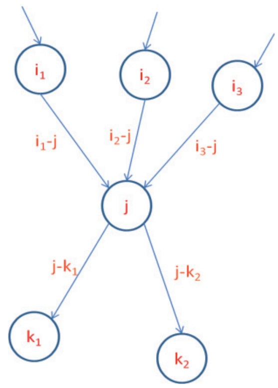

Fig. 1. Node *j* connections

Using the same approach, it is also easy to calculate the CC_j in the presence of leakages in the supply system. A 'leakage node' should be inserted in the graph, having no transfer cost and a dummy request equal to the estimated water loss, as shown in Fig. 2. The leakage node's predecessor will be charged with the lost water cost. The weighted cost at the predecessor node *j* is then calculated by dividing the sum of incoming costs by the outgoing flows, taking away leakage, and the equation must be modified as in eq. (3).

In order to correctly evaluate cumulative costs, equations (2) or (3) must be applied in the correct order, starting from supply nodes and ending on demand nodes along the path. The topological order in the analysis of nodes must be preliminarily defined, searching the path between supply and demand nodes. Using the MATLAB® computational environment, the topological order of the nodes are provided by the internal function *Graphtopoorder* (Siek et al., 2002), and equations (2) and (3) are included in the cumulative cost evaluation procedure.

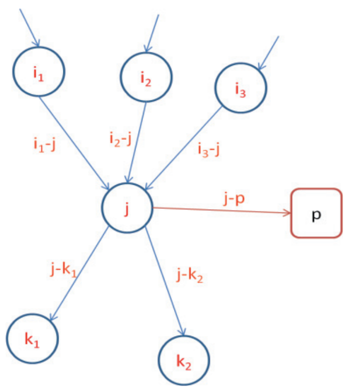

Fig. 2. Leakage node insertion

$$CC_j = \frac{\sum_{i=1}^{I} \left(CC_i + BC_{ij}\right) Q_{ij}}{\sum_{i=1}^{K} Q_{jk} - Q_{jp}} \qquad (3)$$

Synthesizing, data input for the procedure are:

A the adjacency matrix of the graph describing topology of the water system;

Q the matrix of water flows, given by WARGI-SIM outputs;

BC the matrix of basic costs related to every arc of the graph.

Matrices are quadratic *[n x n]*, where *n* is the number of nodes in the graph.

As documented in the following applications, the results of this procedure can define the ***CC*** vector at each node of the graph, at each time step of analysis. In particular, the cumulative cost values of the water are retrieved at the demand nodes.

2.4. Incremental benefits and investments priorities evaluation for leakage reductions

As previously declared, when negotiating for optimal decisions in a system subject to scarce availability of funds, the leakage reduction optimality problem can be modified in finding the priorities of investment for leakage reduction. Priorities between centres (or distribution districts) will be defined following the criteria of maximizing the value of benefit from water loss reduction at each centre for a pre-fixed amount of investment.

Define $k = 1, K$ the set of demand nodes; CC_k their cumulative water costs, retrieved as previously described; D_k the actual water requests at the demand nodes (inclusive of leakages); IC_t the investment cost at decision time t and R_k the expected leakage reduction at the *k-th* centre if spending IC_t at the centre. The modification of a water request (due to leakage reduction) at the *k-th* node requires a new run of WARGI-SIM in order to retrieve new values of flows ***Q*** and to update ***CC*** values; their new values are indicated as ***CC'***.

The investment IC_t will be assigned to the centre k' maximizing incremental benefits IB_k , ($k = 1, K$):

$$IB_{k'} = \max_{k=1,K} \left\{ CC_k \times D_k - CC'_k \cdot (D_k - R_k) - IC_t \right\} \tag{4}$$

Nevertheless, the analysis takes place in a ordinary management optimization framework, therefore the investment at time $t = 1, T$ can be considered divided into several decision steps and considering different amounts of money; moreover, different investment amounts could be necessary for each demand centre at each decision step. Therefore, the maximization of the net benefit-cost ratio BR_k occurring for each centre at each decision step can better express the economical optimality:

$$BR_{k'} = \max_{k=1,K} \left\{ IB_k / IC_k \right\} \tag{5}$$

3. Applications

Two applications of the Cost-Simulation procedure are considered and results are given in the following: first, application to a simple example scheme, then to a real supply system in northwest Sardinia (Italy).

3.1. A simple scheme

To better describe the methodology, it is first applied to a simple system represented in Fig. 3 by a graph of five nodes and six arcs and considering two demands (nodes 4 and 5) and two sources (nodes 1 and 2). The amounts of water initially assigned (sum of net requests and leakages) at nodes 4 and 5 are both equal to10 million cubic metres (Mm^3) and each source, node 1 and 2, could supply up to 10 Mm^3. At the beginning, the distribution efficiency eff_k (net water request divided by assigned) in centre 4 is equal to 40% and in centre 5 is equal to 50%. The connections [2–4] and [1–5] are cheaper but they have an upper bound equal to 5 Mm^3; the basic transfer cost ***BC*** values are given in Table 1.

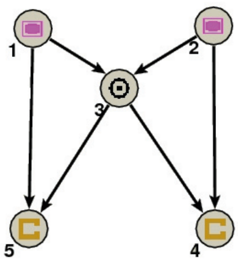

Fig. 3. Simple water scheme.

The previously described procedure applies the cost balance equation (2) and permits evaluation of the cumulative cost vector ***CC*** at each node of the graph. At the first step, the adjacency matrix ***A***, the flow matrix ***Q***, and the basic costs matrix ***BC*** and cumulative cost vector ***CC*** are then given in (6). This simple example considers a unique request pattern and no seasonality.

$$\boldsymbol{A}=\begin{bmatrix}0&0&1&0&1\\0&0&1&1&0\\0&0&0&1&1\\0&0&0&0&0\\0&0&0&0&0\end{bmatrix};\quad \boldsymbol{Q}=\begin{bmatrix}0&0&0&0&5\\0&0&10&5&0\\0&0&0&5&5\\0&0&0&0&0\\0&0&0&0&0\end{bmatrix};\quad \boldsymbol{BC}=\begin{bmatrix}0&0&3&0&2\\0&0&2&1&0\\0&0&0&1&1\\0&0&0&0&0\\0&0&0&0&0\end{bmatrix};\quad \boldsymbol{CC}=\begin{bmatrix}0\\0\\2\\2\\2.5\end{bmatrix} \tag{6}$$

Nodes 1 and 2 have no predecessors and cumulative costs are equal to zero; applying the balance cost equations at node 3, the obtained *CC* value is equal to 2; at node 4 and 5 both the *BC* values of incoming arcs and the *CC* of the predecessor nodes must be considered; the final costs of the water at demand nodes are equal to 2 and 2.5. Retrieved optimal flows are also given in Table 1. Results of the first three steps in investment allocation are given in Table 2: at each decision step incremental benefits *IB* are evaluated for both centres 4 and 5. Investment *IC* could be different for the two demand centres due to different necessary leakage reduction works. At each decision step, the investment is assigned to the node giving the higher value of net benefit-cost ratio, as given by eq. (5).

Table 1. BC, upper bounds and initial flows in transfer arcs

Arc	BC	Upper bound	Flow
1-3	3	-	0
1-5	2	5	5
2-3	2	-	10
2-4	1	5	5
3-4	1	-	5
3-5	1	-	5

Table 2. Investment attribution at each decision step

Step	Node	*D*	*CC*	*CC* x *D*	*eff*	*IC*	*D - R*	*CC'*	*CC'(D-R)*	*IB*	*BR*	Allocation
I	Node 4	10	2	20	40%	1	9	1.89	17.01	1.99	1.99	Node 4
	Node 5	10	2.5	25	50%	2	9	2.44	21.96	1.04	0.52	
II	Node 4	9	1.89	17.01	44%	1	8	1.75	14.00	2.01	2.01	Node 4
	Node 5	10	2.5	25	50%	2	9	2.44	21.96	1.04	0.52	
III	Node 4	8	1.75	14	50%	2	7	1.57	10.99	1.01	0.505	Node 5
	Node 5	10	2.5	25	50%	2	9	2.44	21.96	1.04	0.52	

3.2. The Temo water supply system

The Cost-Simulation procedure was then applied to the *Temo* supply system for urban demands located north-west of the Sardinia region (Italy). The system is characterized by demand nodes representing small towns and villages. As sketched in Fig. 4 using the WARGI graphical interface, the system supplies 10 urban centres, nine of which are connected to a treatment plant for the water coming from the *Temo* reservoir, which is the main water source in the system. There are two other sources: the *Sant'Antioco* springs and the *Campeda* wells. The town of *Scano* is supplied only by the springs; the town of *Macomer* could be supplied by all sources. To deliver water, in addition to the wells' pumps, eight pumping stations are located in the system. Served population, theoretical water demand, consumption and efficiency are given in Table 3.

The *Temo* supply system must be analysed considering typical seasonal behaviour, dividing the year into four time periods. Regarding urban demands, requests from nine centres can be considered constant during seasons; only the town of *Bosa* increases water consumption in the summer, due to touristic demand (Table 4).

Significant seasonality must be also considered defying flows availability from spring and wells sources. The sources of *Sant'Antioco* and *Campeda* have different behaviour during the year: in winter they supply the maximum resource, in summer the minimum, and in the other seasons an intermediate quantitative (Table 4). Note that the *Temo* treatment plant is linked to a reservoir with enough capacity to assure inter-annual regulation and no seasonal variability must be considered for it; the only restriction is related to its production capacity. Consequently, in standard conditions the *Temo* water system does not suffer water shortage; nevertheless, economic efficiency conditions are to be reached. Table 7 gives details of the capacity of pump stations, treatment and pumping basic costs.

After running the WARGI-SIM simulation model in the actual situation of water distribution efficiency in the centres, the obtained seasonal optimal flows are reported in Table 6. By implementing the previously described procedure, the adjacency matrix ***A***, flow matrix ***Q*** and ***BC*** matrix are retrieved. In this case, to define flows ***Q***, a tri-dimensional matrix is needed to give flows in the four time steps. Applying equations (2) and (3) in the right node order, the procedure was implemented in MATLAB® using the *Graphtopoorder* internal function; the ***CC*** are retrieved for each node.

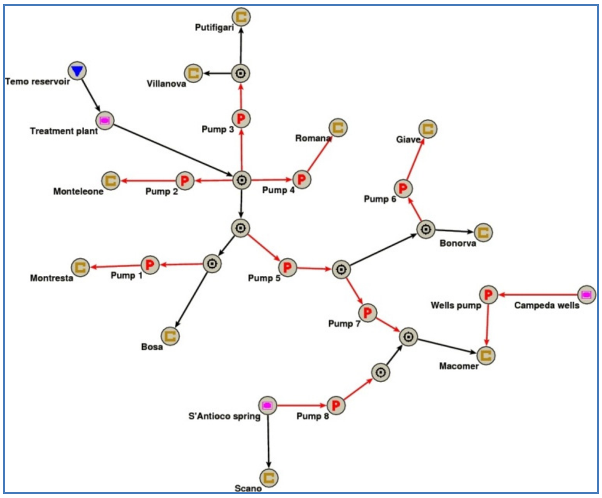

Fig. 4. Temo water system scheme using WARGI graphical interface

Final results for demand nodes are reported in Table 7: the ***CC*** values and the evaluated annual cost for all demand nodes are given in the table, apart from the values related to the *Macomer* demand centre. This because nodes in Table 7 are supplied only by the *Temo* reservoir source, while *Macomer* is also supplied by other sources, two of which have different water availability during the year. *Macomer* is therefore charged by different ***CC*** at each season (Table 8). All values in Table 6, Table 7 and Table 8 refer to the initial situation regarding water consumption, flows and costs. To define priorities, results of the initial decision steps after assigning requested values in investment allocation to each centre are given in Table 9. Information on funds' availability and leakage reduction investment requirements at each centre and at each decision step were provided by Abbanoa s.p.a., the water management company. The incremental benefits and benefit-cost ratio are evaluated for all centres and the investment *IC* is assigned to the centre giving the higher value of *BR*, following eq. (5). Considering funding availability of about 100,000 euro/year for ordinary leakage reduction activities, in Table 10 is given investment attribution in the annual time horizon, considering 30 decision steps. The cumulate *IB* value of 440,535 Euros per year is a global evaluation of the annual benefits in reducing leakages in the system.

Table 3. Annual water requests, consumptions and efficiencies

Demand node	Inhabitants	Annual water request [l/s]	Annual Water consumption [l/s]	Efficiency
Romana	585	1.4	2.6	53%
Villanova	2'405	5.6	10.0	56%
Putifigari	753	1.7	2.5	69%
Monteleone	126	0.3	0.8	34%
Montresta	559	1.3	5.2	25%
Bonorva	3'742	8.7	17.4	50%
Giave	597	1.4	2.9	47%
Scano	1'592	3.7	11.9	31%
Macomer	10'670	23.3	67.6	37%
Bosa	8'133	18.8	67.5	28%
TOT	29'162	62.2	188.4	33%

Table 4. *Bosa* and sources seasonality

	Gen-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Bosa water request [l/s]	60.0	70.1	79.9	60.0
Sant'Antioco springs [l/s]	65.0	55.0	15.0	55.0
Campeda wells [l/s]	25.0	20.0	15.0	20.0

Table 5. Infrastructures basic costs and transfer capacities

Infrastructure	Basic costs [€/m^3]	Capacity [l/s]
Treatment plant	0.11	300
Campeda wells pumps	0.20	30
Pump n.1	0.30	6
Pump n.2	0.30	2
Pump n.3	0.65	15
Pump n.4	0.10	3
Pump n.5	0.39	90
Pump n.6	0.14	5
Pump n.7	0.07	80
Pump n.8	0.33	15

Table 6. WARGI optimal flows

Transfer from infrastructures	Flow [l/s]			
	Gen-Mar	Apr-Jun	Jul-Sep	Oct-Dec
Treatment plant	129	144	170.9	134
Campeda wells pumps	25	20	15	20
Sant'Antioco spring	100	80	50	80
Pump n.1	5.2	5.2	5.2	5.2
Pump n.2	0.8	0.8	0.8	0.8
Pump n.3	12.5	12.5	12.5	12.5
Pump n.4	2.6	2.6	2.6	2.6
Pump n.5	47.9	52.9	69.8	52.9
Pump n.6	2.9	2.9	2.9	2.9
Pump n.7	27.6	32.6	49.5	32.6
Pump n.8	15	15	3.1	15

Table 7. Cumulative cost for demand nodes at the initial step

Demand node	CC [€/mc]	Annual cost [€/year]
Romana	0.21	17'219
Villanova	0.76	239'674
Putifigari	0.76	59'918
Monteleone	0.41	10'344
Montresta	0.41	67'235
Bosa	0.11	234'155
Bonorva	0.50	274'363
Giave	0.64	58'531
Scano	0.00	0

Table 8. Macomer cumulative cost at the initial step

Demand node	CC [€/m^3]					Annual cost [€/year]
	Gen-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Mean	
Macomer	0.380	0.407	0.477	0.407	0.418	885'834

Table 9. Investment [€/year] attribution in the first and second decision step

Step	Centre	*D*	*CC*	*CC* x *D*	*eff*	*IC*	*D - R*	*CC'*	*CC'(D-R)*	*IB*	*BR*	Allocation
1	Romana	2.6	0.21	17'219	54%	6'000	1.6	0.21	10'596	622	0.10	
	Villanova	10	0.76	239'674	56%	6'000	9	0.76	215'706	17'967	2.99	
	Putifigari	2.5	0.76	59'918	68%	6'000	1.5	0.76	40'745	13'173	2.20	
	Monteleone	0.8	0.41	10'344	38%	3'000	0.3	0.41	3'879	3'464	1.15	
	Montresta	5.2	0.41	67'235	25%	3'000	4.2	0.41	54'305	9'929	3.31	
	Bosa	67.5	0.11	233'114	28%	3'000	66.5	0.11	229'645	468	0.16	
	Bonorva	17.4	0.50	274'363	50%	6'000	16.4	0.50	258'595	9'768	1.63	
	Giave	**2.9**	**0.64**	**58'531**	**48%**	**3'000**	**1.9**	**0.64**	**38'348**	**17'183**	**5.73**	**Giave**
	Macomer	67.2	0.418	885'834	35%	3'000	66.2	0.416	868'476	14'357	4.79	

2	Romana	2.6	0.21	17'219	54%	6'000	1.6	0.21	10'596	622	0.10	
	Villanova	10	0.76	239'674	56%	6'000	9	0.76	215'706	17'967	2.99	
	Putifigari	2.5	0.76	59'918	68%	6'000	1.5	0.76	40'745	13'173	2.20	
	Monteleone	0.8	0.41	10'344	38%	3'000	0.3	0.41	3'879	3'464	1.15	
	Montresta	5.2	0.41	67'235	25%	3'000	4.2	0.41	54'305	9'929	3.31	
	Bosa	67.5	0.11	233'114	28%	3'000	66.5	0.11	229'645	468	0.16	
	Bonorva	17.4	0.50	274'363	50%	6'000	16.4	0.50	258'595	9'768	1.63	
	Giave	1.9	0.64	38'348	74%	6'000	1.4	0.64	28'256	10'092	0.68	
	Macomer	**67.2**	**0.416**	**885'834**	**35%**	**3'000**	**66.2**	**0.416**	**868'476**	**14'357**	**4.79**	**Macomer**

Table 10. Final attribution of annual investments [€/year]

Step	Centre	*eff* *(system)*	*IC*	*IB*	Cumulate *IC*	Cumulate *IB*
1	Giave	35.8%	3'000	17'183	3'000	17'183
2-23	Macomer	36.0%-40.6%	63'000	314'353	66'000	331'537
23-25	Montresta	40.9%-41.4%	9'000	29'789	75'000	361'326
26-28	Villanova	41.7%-42.3%	18'000	53'902	93'000	415'228
29	Putifigari	42.5%	6'000	13'173	99'000	428'402
0	Macomer	42.8%	6'000	12'133	105'000	440'535

References

Ahuja R.K., Magnanti T.L., Orlin J.B., 1993. Network Flows. Prentice Hall, Englewood Cliffs.

Ahuja R.K., Orlin J.B., Sechi G.M., Zuddas P.,1999. Algorithms for the Simple Equal Flow Problem. Management Science, vol. 45, p. 16, ISSN: 0025-1909.

Deidda D.,2003. Metodologia para la Asignacion de los Costes de los Servicios del Agua Basada en la Teoria de Juegos Cooperativos. PHD Thesis, UPV – Valencia, Spain.

Farley M., Trow S., 2003. Losses in water distribution networks. A practitioner's guide to assessment, monitoring and control. IWA Publishing, London.

Lambert and Lalonde, 2005. Using pratical predictions of economic intervention frequency to calculate short-run economic leakage level, with or without pressure management, Proc. Of IWA Specialised Confeence Leakage 2005, Halifax.

Manca A., Sechi G.M., Sulis A., Zuddas P., 2004. Complex Water Resources System Optimization Aided by Graphical Interface. VI International Conference of Hydroinformatics, Singapore.

Pallottino, S., Sechi, G.M., Zuddas, P., 2005. A DSS for water resources management under uncertainty by scenario analysis. Environmental Modelling & Software 20, 1031e1042.

Pearson, D., & S. W. Trow (2005). Calculating economic levels of leakage. Proceedings of Leakage 2005 Conference, Halifax, Canada, IWA

Sechi G.M., Zuddas P., 2000. WARGI: Water Resources System Optimization Aided by Graphical Interface. In W.R. Blain and C.A. Brebbia: Hydraulic Engineering Software. WIT-PRESS.

Siek J.G., Lee L-Q., Lumsdaine A., 2002. The Boost Graph Library User Guide and Reference Manual. Upper Saddle River, NJ:Pearson Education.